Abstract: Cereal grains with their high starch content are fed to livestock predominantly as a source of energy for rapid growth or high milk yield and also for subsistence in times of poor pasture availability. Results from the Premium Grains for Livestock Program show there are large variations across cereal grain species, cultivars, individual grain samples and animal types in the energy released during digestion and in the amount of grain eaten. The digestive system of an animal has a major effect on the energy value of individual barley samples. Some samples provide more energy for ruminants but less for pigs and poultry, and vice versa. Several grain characteristics that contribute to these differences have been identified. Chemical composition of the grain and nature of the endosperm cell walls have a major impact on the energy made available to different animal types. The rate of starch digestion and chances of causing acidosis are important characteristics for determining the energy value of barley for ruminants. Specific grain characteristics that could be included in barley breeding programs for different types of livestock production have been identified. NIR calibrations have been developed for many of these characteristics and should result in more effective evaluation of grains within breeding programs and for sale to the livestock industries.
Feed Uses for Barley


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Abstract:

Cereal grains with their high starch content are fed to livestock predominantly as a source of energy for rapid growth or high milk yield and also for subsistence in times of poor pasture availability. Results from the Premium Grains for Livestock Program show there are large variations across cereal grain species, cultivars, individual grain samples and animal types in the energy released during digestion and in the amount of grain eaten. The digestive system of an animal has a major effect on the energy value of individual barley samples. Some samples provide more energy for ruminants but less for pigs and poultry, and vice versa. Several grain characteristics that contribute to these differences have been identified. Chemical composition of the grain and nature of the endosperm cell walls have a major impact on the energy made available to different animal types. The rate of starch digestion and chances of causing acidosis are important characteristics for determining the energy value of barley for ruminants. Specific grain characteristics that could be included in barley breeding programs for different types of livestock production have been identified. NIR calibrations have been developed for many of these characteristics and should result in more effective evaluation of grains within breeding programs and for sale to the livestock industries.

Key Words: Barley, available energy, ruminants, pigs, poultry

Introduction:

Cereal grains with their high starch content are fed to livestock predominantly as a source of energy. Barley and wheat are the grains most commonly used by Australian livestock industries. During 2004 approximately 2000 kt of both barley and wheat were used by livestock which, when combined, represented around 60% of all cereal grains fed (1). Oats (20%), sorghum (10%) and triticale (10%) made up the other cereal grains used by the livestock industries. Approximately 40% of the barley was fed to feedlot cattle, 34% to dairy cows, 20% to pigs and 6% to grazing ruminants. Less than 1% was used for poultry. Large differences have been reported between individual samples of barley in the energy made available and in performance of pigs (2) and cattle (3). The extent of variation in the energy value of cereal grains and the factors contributing to this variation have been investigated in the Premium Grains for Livestock Program.

Methods:

Over 3300 cereal grains with a wide range in chemical and physical characteristics were collected. The grains were from germplasm archives, plant breeder collections, specifically grown crops or selected because of drought, frost damage or pre-harvest germination. All grains were scanned with near infrared spectroscopy (NIR) and the extent of digestion of selected grains examined with in vitro techniques simulating rumen function and intestinal digestion. Over 190 grains were fed to animals and approximately 40 of these including samples of wheat, barley, oats, triticale and sorghum were fed across ruminants (sheep and cattle), pigs, broiler chickens and laying hens. The energy from grains made available following digestion was measured in all animal types, whereas voluntary intake was measured in cattle, broilers, layers and pigs. A comprehensive chemical and physical analysis was conducted on all grains fed to animals.

Definition of the energy value of a grain and effect of the digestive process:

The value of a grain as a source of energy to an animal depends on the total amount of energy made available for metabolism (MJ/d), which is determined primarily by the energy available from digestion (MJ/kg) and the amount of grain consumed (kg/d). Energy available following digestion is normally defined as the
energy in chemical components, digested and absorbed, which can be used in metabolic processes within the animal. The value of energy released during digestion varies substantially depending on whether digestion is a result of animal secreted enzymes or enzymes of microbial origin. In the latter case, dietary constituents are converted into growing microbes, volatile fatty acids and other compounds with the release of methane, ammonia and heat of fermentation. This microbial fermentation process can result in loss from the animal of 10-20% of the energy in digested material depending on diet composition, conditions of fermentation and species of microbes present. Nevertheless, the fermentation process is important for some animals because microbial enzymes can cleave chemical bonds in cellulose, arabinoxylans, β-glucans and other plant materials that cannot be broken by enzymes secreted by mammals and birds.

The value of microbial fermentation to an animal depends on the proportion of compounds in the diet that cannot be digested by animal enzymes and the location of the fermentation process within the digestive tract. Digestion involving microbial activity is most appropriate for animals consuming diets high in plant fibre. Feed consumed by ruminants is subjected to microbial fermentation within the rumen before it passes to the stomach and small intestines where animal enzymes are secreted. The starch in cereal grains is first subjected to microbial action and, if readily accessible to microbial enzymes, can result in a rapid digestion, increased acid production, low pH and lactic acidosis with severe disruption to the digestive process, a reduction in plant fibre digestion and in feed intake. Accessibility of starch granules to microbial enzymes depends on disruption to endosperm cell walls and the protein matrix during grain processing, mastication or microbial digestion. The greatest amount of energy would be made available to ruminants when starch granules are exposed for animal enzymic digestion as they leave the rumen.

Grain consumed by pigs passes to the stomach and small intestine where it is exposed to animal secreted enzymes before moving to the hind-gut which can contain high concentrations of microbes. Pigs masticate feed poorly and unless the grain is processed before ingestion to disrupt the endosperm cell walls, large quantities of starch can be fermented in the hind-gut resulting in loss of energy, reduced feed intake and susceptibility to enteric diseases. Poultry do not have a significant microbial population within the digestive tract and there is insignificant digestion of non-starch polysaccharide components in grain. Poultry have a gizzard where intense muscular contractions disrupt the integrity of cell walls and readily expose starch granules to enzymes in the small intestines. However, the high dry matter content of poultry digesta and the short transit time of digesta through the gut mean that non-starch polysaccharides, particularly long chain, increase digesta viscosity and reduce accessibility of enzymes to the starch granules.

Energy released from grains during digestion (available energy content, MJ/kg) is expressed in this paper as digestible energy (DE, energy in feed less energy in faeces) for pigs, apparent metabolisable energy (AME, energy in feed less energy in faeces which includes uric acid) for poultry and metabolisable energy (ME, energy in feed less energy in faeces, urine and expelled methane) for ruminants.

Variation in the available energy content of barley compared with other cereal grains:

There are large variations across cereal grain species, cultivars, individual grain samples and animal types in the available energy content of cereal grains (Figure 1). Barley was digested with different efficiencies relative to the other cereal grains. When compared with wheat, triticale, sorghum and oats, barley had the lowest mean available energy content for broilers. Oats were not fed to pigs, but barley had the lowest mean available energy content of all grains examined. The mean available energy content of barley was lower than sorghum, wheat and triticale, but higher than oats for laying hens and was lower than wheat and triticale, but higher than oats and sorghum for cattle.

There were substantial differences in the available energy content of individual barley samples when compared across animal types. Pigs extracted more energy from barley than the other animal types examined, whereas cattle generally extracted the least energy (Figure 2). Correlations for the available energy content of barley between broilers and the other animals were 0.77 for layers, 0.56 for pigs and 0.09 for cattle. The correlation between pigs and cattle was 0.71. These correlations suggest that there are considerable differences between animal types in their capacity to digest individual barley samples, with some being relatively more digestible by ruminants than pigs or poultry and vice versa. Close examination of Figure 2 shows that barley sample 1 was relatively poorly digested by all animal types. The available energy content of sample 4 was low for cattle and pigs, and medium for broilers and layers, whereas sample
5 was low for cattle, high for poultry and medium for pigs. Sample 17 was high for cattle, low for pigs and very low for poultry, whereas sample 18 was high for cattle and pigs, low for broilers and medium for layers. These differences in available energy content of the grains can be explained through knowledge of the digestive system of each animal type and the chemical and physical characteristics of the grain samples.

Figure 1. Available energy content of individual grain samples fed to animals ad libitum.

Figure 2. Available energy content of 18 barley samples for different animal types fed ad libitum.

The extent of digestion of a grain by an animal depends on the adequacy of enzymes within the digestive tract capable of breaking specific chemical bonds, accessibility of the enzymes to the chemical components, and the time enzymes and the grain components are associated. Much of the variation between grains in energy digestion can be explained by gross chemical composition of the grain such as its starch and fibre contents. Sample 1 in Figure 2, with low energy availability in all animals, was frost affected and was low in starch and high in fibre. Other grain characteristics, particularly the endosperm cell walls and protein matrix, can affect the accessibility of enzymes to starch. Sample 4, with low energy content for pigs, had high hull content and thick cell walls which presumably were not fully disrupted during mastication. High viscosity of digesta caused by excessive cell wall non-starch polysaccharides, particularly in broiler chickens, can reduce the accessibility of enzymes to grain components and the time enzymes have to hydrolyse starch. Sample 5, with high available energy content for broilers was partially sprouted and had extremely low whole grain viscosity values. Sample 17, which was poorly digested by broilers and pigs, but well digested by ruminants, contained high concentrations of β-glucans and arabinoxylans and had the highest whole grain final viscosity. This is indicative of thick endosperm cell walls and low digestibility in broilers, whereas the cell wall components would be readily digested by rumen microbes. There was a strong negative correlation (-0.62; P<0.01) between AME in broilers and arabinoxylan content. Sample 18, with high available energy for pigs and ruminants, but low in broilers, was a naked grain with high whole grain viscosity.

Variation in total available energy intake from barley based diets:

Correlations for total intake of available energy from barley based diets were -0.64 between broilers and pigs, -0.71 for broilers and cattle, and 0.33 for cattle and pigs. These correlations emphasise further that
individual barley samples are most suitable for particular forms of livestock production. Available energy intake from barley for pigs was negatively correlated (P<0.01) with several cell wall characteristics (r = -0.88 cellulose, -0.83 soluble arabinoxylans, -0.63 β-glucans, -0.60 phytic acid). Available energy intake by broilers was negatively correlated (P<0.01) with whole grain viscosity (r, -0.59), condensed tannins (r, -0.51) and oligosaccharides (r, -0.48). Total ME intake for cattle was positively correlated with characteristics of cell walls that slow the rate of rumen fermentation (r=0.83 soluble arabinoxylans, 0.75 whole grain viscosity, 0.71 kernel hardness) and negatively related to high fibre content (r=-0.79 cellulose, -0.65 crude fibre).

A comparison of barley with other cereal grains shows that although the mean available energy content was less than other grains for pigs, the intake of diets containing barley was greatest, which resulted in the highest total energy intake from barley. Nevertheless, a greater proportion of digestion occurred in the hind gut of pigs fed barley based diets with the mean ratio of energy digested by the end of the small intestine to digestion across the whole gut being 0.77 for barley, 0.82 for triticale, 0.85 for wheat and 0.87 for sorghum. Because approximately 15% of the energy released through microbial fermentation is lost in heat and methane, total energy available for productive purposes was similar for pigs fed barley, wheat and triticale based diets, but was less for sorghum which had a low mean intake. Although similar rates of growth could be expected from pigs fed barley, wheat and triticale based diets, the low digestibility and high fermentation losses from barley would result in a lower feed conversion efficiency than for the other grains.

Barley is recognised to be a poor grain for broiler chickens because it had the lowest mean available energy content and lowest mean intake for all the cereal grain species examined. High concentrations of long-chain, soluble, non-starch polysaccharides within the barley endosperm increase digesta viscosity, slow penetration of starch digesting enzymes, reduce the rate of passage through the digestive tract and limit feed intake. Exogenous xylases and glucanases are used commercially to hydrolyse long-chain non-starch polysaccharides. The mean intake of available energy by cattle tended to be less for barley than for wheat or triticale based diets, but was considerably higher than for sorghum. The total intake of ME tended to be negatively correlated with an acidosis index which suggests that within a grain species, those grains with similar composition, slower rates of fermentation in the rumen and increased digestion of starch in the small intestine provide greater amounts of energy for production.

Conclusions:

Characteristics of barley grain determine its capacity to provide energy for specific types of animals. Selection criteria for breeding barley most suitable for each type of livestock can be developed from the findings presented. Barley lines with low hull content, thin and fragile cell walls that are low in soluble arabinoxylans and β-glucans and have readily accessible starch granules should be selected for pigs. For poultry, lines with low whole grain viscosity, indicating short-chain cell wall non-starch polysaccharides, and low levels of condensed tannins are needed. However, for ruminant production, cultivars with thick cell walls, high concentrations of soluble arabinoxylans, hard kernels and slow rates of starch degradation in the rumen as indicated by a low “acidosis index’ are required. NIR calibrations have been developed within the Premium Grains for Livestock Program for predicting the available energy intake index for broilers, layers, pigs and poultry, and other grain characteristics specifically mentioned including an acidosis index. These NIR calibrations should assist greatly the ability to screen grains within barley breeding programs and for assessing the livestock production system that is most appropriate for any grain sample.

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